Safety Evaluation Report

Safety Basis for Certification of Project Maximus LEU Type A Drums as a Type AF Packaging Configuration, ORNL/NTRC-020, Vol. 1 to 2, Rev. 1, February 2007

Docket No. 06-48-9865

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INTRODUCTION

In a letter to Dr. James Shuler dated June 30, 2006, the Oak Ridge National Laboratory (ORNL) requested certification of a DOT 7A Type A drum for low-enriched uranium (LEU) oxide contents as a Type AF packaging configuration. The certification is requested for shipment of the LEU oxide contained in seventy-five (75) 55-gallon Type A drums. Accompanying the letter is a document *Safety Basis for Certification of Project Maximus LEU Type A Drums as a Type AF Packaging Configuration*, ORNL/NTRC-020, Vol. 1 to 3, Rev. 0, June 2006. The letter stated that the document follows the same rationale employed by the Washington Savannah River Company (WSRC) for EM-60 certification of a similar packaging configuration for one-time, one-way shipments of 227 LEU oxide drums from the Savannah River site to the Nevada Test site. For those shipments, EM-60 has issued a Certificate of Compliance (CoC) USA/9976/ AF (DOE), Rev. 1, which lists the technical basis document *Savannah River Site Request for Department of Transportation Exemption (U)*, WSRC Document No. OBU-TRA-2004-00022, Rev. 2, June 8, 2006. EM-60 also issued the Safety Evaluation Report (SER) *Request for Change to Certificate of Compliance USA/9976/AF (DOE), Rev. 0 to Add Steel to Drums for Low Enriched Uranium Oxide Shipment*, Docket No: 06-31-9976, September 15, 2006. The SER provides the EM-60's approval basis for the CoC USA/9976/AF (DOE), Rev. 1.

The EM-60 staff completed the review of the ORNL/NTRC-020, Rev. 0 document and found it deficient in providing the necessary and sufficient technical basis that meets the regulatory safety requirements in 10 CFR Part 71 and 49 CFR 173 for a Certificate of Compliance. The major deficiencies were identified in the Q0 review report,[1] along with comments that may be considered in the revision of ORNL/NTRC-020, Rev. 0. After several conference calls between the applicant and the EM-60 staff between December 2006 and February 2007, a revised document, ORNL/NTRC-020, Rev. 1,[2] was submitted to EM-60 in March, 2007. This Safety Evaluation Report documents the results of the review of ORNL/NTRC-020, Rev. 1 and the approval basis for the CoC USA/9865/AF-96 (DOE).

PACKAGING AND CONTENTS

The packaging is a DOT 7A Type A drum containing a square wooden box (overpack) that surrounds an inner metal canister, which contains low-enriched uranium (LEU) oxide. The packaging consists of a 16-gauge, 55-gallon galvanized carbon steel drum with three rolling hoops, manufactured to the ORNL Specification No. 100-1A2-007, which is included as Appendix C in ORNL/NTRC-20, Rev. 1. The drum has a 16-gauge removable lid, a 12-gauge closure ring with 5/8-inch-diameter bolt and nut, and elastomer gasket. The inner metal canister is approximately 12-in diameter, 20-in height, 0.06-in wall, and is likely made of either carbon steel or stainless steel. The wooden box has approximate dimensions of 15-in by 15-in square and 25-in tall. The wooden box consists of layers of wood boards that are nailed and tied together with four long bolts and two angle steels on the top of the wooden box for lifting and handling (See Figures 1 to 7 in Section 1.3 of ORNL/NTRC-20, Rev. 1.). The tare weight of the wooden box is 63.0 kg. The tare weight of the wooden box includes the inner metal canister (7.4 ± 0.3 kg) and other steel mass for the angle steels, vertical rods, bottom metal plate, and nails

(18.5 kg estimated total). The mass of the outer container Type A drum is estimated to be 18.236 kg based on the dimensions of the drum and a steel density of 7.82 g/cm^3. The estimated gross weight of the Type A drum, including the wooden box and LEU oxide is ≈ 109 kg (63.0 kg +18.236 kg +27.3 kg), where the detailed inventory of the LEU oxide packages is given in Table 4 of ORNL/NTRC-20, Rev. 1.

Section 2.1 of ORNL/NTRC-20, Rev. 1 provides description of the LEU oxide. The reported net weight of the LEU oxide per canister has a range of 27.3 ± 0.1 kg. Based on the reported uranium weight fraction (0.8703 grams uranium per grams of oxide) and a ^{235}U enrichment of 2.593 %, a typical canister would contain 23.759 kg U and 616 g of ^{235}U. Table 4 in ORNL/NTRC-20, Rev. 1 shows the measured ^{235}U enrichment values varying between 2.321 to 2.872% for the 75 canisters containing the LEU oxide. The measurements of ^{235}U enrichment were performed using a Canberra U-Pu Inspector Low Energy Germanium (LEGe) detector with Multi-Group Analysis of Uranium (MGAU) software/portable workstation. (A photo of the system is shown in Fig. 15 of ORNL/NTRC-20, Rev. 1.) Limited QA calibration data for the Canberra Model system are shown in Table 6 of ORNL/NTRC-20, Rev. 1. Comparison of the measured values of ^{235}U enrichment (2.968% average) to a calibration source of known enrichment (2.95%) showed reasonable agreement, with the relative differences within the declared range of accuracy of 1-2% (MGAU – Multi-Group Analysis Software for Uranium, www.canberra.com/products/841.asp)

CRITICALITY SAFETY EVALUATION

The federal regulations that govern the transport of fissile materials are 10 CFR 71.22 *General license: Fissile material*; 10 CFR 71.55 *General requirements for fissile material packages*; and 10 CFR 71.59 *Standards for arrays of fissile material packages*.

10 CFR 71.22 *General license: Fissile material.* The Project Maximus LEU oxide package application does **NOT** meet the general license provisions in 10 CFR 71.22, because the applicant is not a licensee of NRC and does not have a quality assurance program approved by NRC as satisfying the provisions of Subpart H of 10 CFR 71. Furthermore, the LEU oxide package does not meet the mass limit requirements for general license packages containing ^{235}U of known enrichment per 10 CFR 71.22 (e). For the range of ^{235}U enrichments of the LEU oxide between 2.321 and 2.872% (Table 4 in ORNL/NTRC-20, Rev. 1), the mass limit of ^{235}U, according to Table 71-2 in 10 CFR 71, is bracketed by 246 g and 150 g for ^{235}U enrichments of 2% and 3%, respectively. Each of the seventy-five 55-gallon Type A drums contains 616 g of ^{235}U (nominal) that exceeds the interpolated mass limits by a factor between ≈ 2.6 and 4.2.

10 CFR 71.55 *General requirements for fissile material packages.* 10 CFR 71.55 is under Subpart E – Package Approval Standards of 10 CFR Part 71. 10 CFR 71.55(d) and (e) state that a package used for the shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in 10 CFR 71.71 *Normal conditions of transport* (NCT) and 10 CFR 71.73 *Hypothetical Accident conditions* (HAC) the contents and package shall be subcritical. Maximum reactivity is assumed for the most reactive credible configuration consistent with the chemical and physical form of the material, moderation by water to the most

reactive credible extent, and close full reflection of the containment system by water on all sides. Since the Type A drum is **NOT** designed and constructed to withstand the tests specified in 10 CFR 71.73 for HAC, and since it is difficult to define the most reactive credible configuration under HAC without testing, it is common and conservative to calculate a spherical safe mass limit for the fissile material of known ^{235}U enrichment, assuming optimal water moderation and full water reflection. (For a given mass of fissile material, a spherical geometry has the smallest surface-to-volume ratio which generally minimizes neutron leakage and increases reactivity.)

Section 4 of ORNL/NTRC-20, Rev. 1 describes the methodology and calculations of the spherical safe mass limits for 2.9% ^{235}U enriched LEU oxide. These calculations assumed a water-reflected, homo-geneous mixture of UO_2 and water in a spherical configuration for which the 2.9% ^{235}U enrichment bounds those of the LEU oxide (2.321 to 2.872% in Table 4, ORNL/NTRC-20, Rev. 1). The calculations were performed using the SCALE 5 code, and the validation of its key module, KENO-V.a, against critical experiments is given in Table 8 of ORNL/ NTRC-20, Rev. 1. The lowest calculated effective neutron multiplication factor, k_{min} = 0.9921, and the combined uncertainty of k_{min} (0.005) from the calculations against 50 benchmark criticals (Table 8) are used in the following formula to calculate a Upper Subcriticality Limit (USL):

$$USL = k_{min} - \text{uncertainty of } k_{min} - NPM - \Delta_{SM} - \Delta_{AOA}$$

where NPM, Δ_{SM} , and Δ_{AOA} are the non-parametric margin (0.01), subcritical margin (0.05), and margin for extension of the area of applicability (0.0), respectively. Substituting the numerical values of these parameters into the formula obtains

$$USL = 0.9921 - 0.005 - 0.01 - 0.05 - 0 = 0.9271$$

The USL value of 0.9271 is used as a conservative criterion for the determination of the spherical safe mass limits shown in Table 7 of ORNL/NTRC-20, Rev. 1. Altogether thirteen cases were calculated with the volume fraction of water in the UO_2-water mixture varying between 15 and 90%. (The corresponding ratio of H: ^{235}U varied between 16.4 and 836.9, respectively.) Figure 1 below is a plot of the results of Table 7 showing that the mass of ^{235}U in a USL sphere drops off significantly with increasing volume fraction of water, reaching a minimum at H: ^{235}U = 526.9 (or 85% volume fraction of water in the UO_2-water mixture). The lowest value of ^{235}U mass obtained in the USL sphere calculations is 1.685 kg, which bounds the total ^{235}U mass of 1.385 kg in <u>two</u> LEU oxide packages that contain the largest amount of ^{235}U. (i.e., Overpack drum no. P0010 and P0039 in Table 4, ORNL/NTRC-20, Rev. 1)

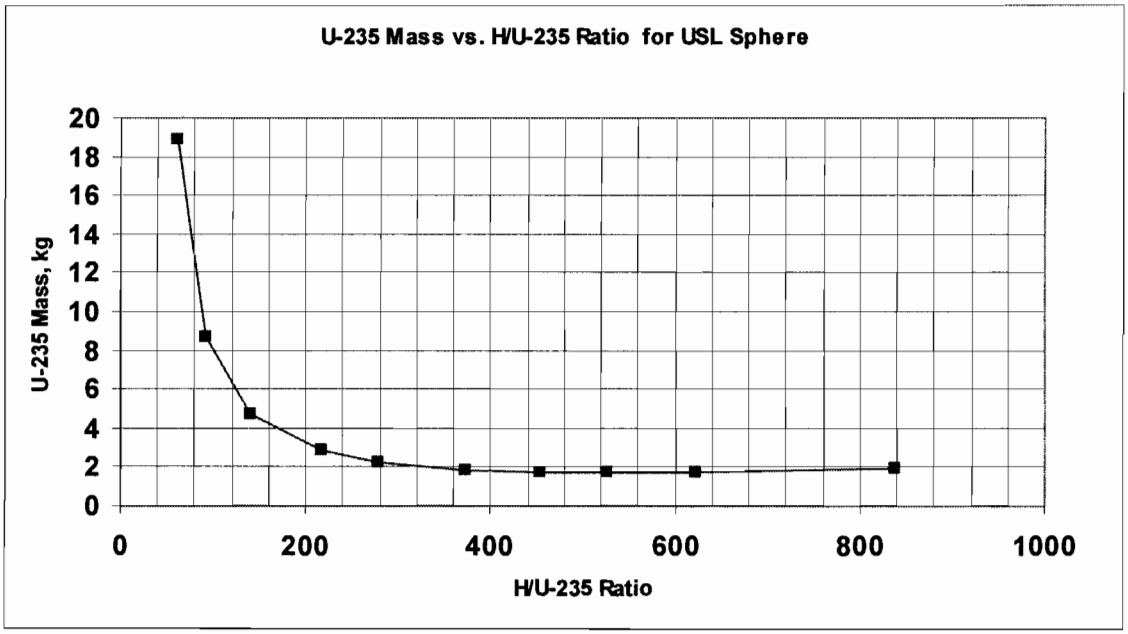

Figure 1. U-235 mass versus H/U-235 ratio for a homogeneous mixture of UO_2 and water in a spherical configuration with 30 cm of water reflection that has $k_{eff} + 2\sigma < 0.9271$ (USL sphere)

The EM-60 staff performed an independent KENO calculation to confirm the results in Table 7. For the case of 85% volume fraction of water in the UO_2-water mixture, the calculated k_{eff} is 0.92512 (±0.00043), versus 0.92504 (±0.00045) found in the output file of Case sp_85 in ORNL/NTRC-20, Rev. 1. Both sets of results give values of $k_{eff} \pm 2\sigma$ below the USL limit of 0.9271.

The EM-60 staff also performed additional KENO calculations to confirm independently that any two of the 75 LEU oxide packages will remain subcritical under HAC. The calculations assumed a total amount of UO_2 (with 1.385 kg ^{235}U) leaking from two LEU oxide packages and mixing homogeneously with water in a spherical configuration, with varying water moderation and full (30 cm thick) water reflection. The most reactive configuration occurs near the water volume faction of 87% (Fig. 2) with a calculated maximum $k_{eff} + 2\sigma$ of 0.89703, which is well below the USL of 0.9271.

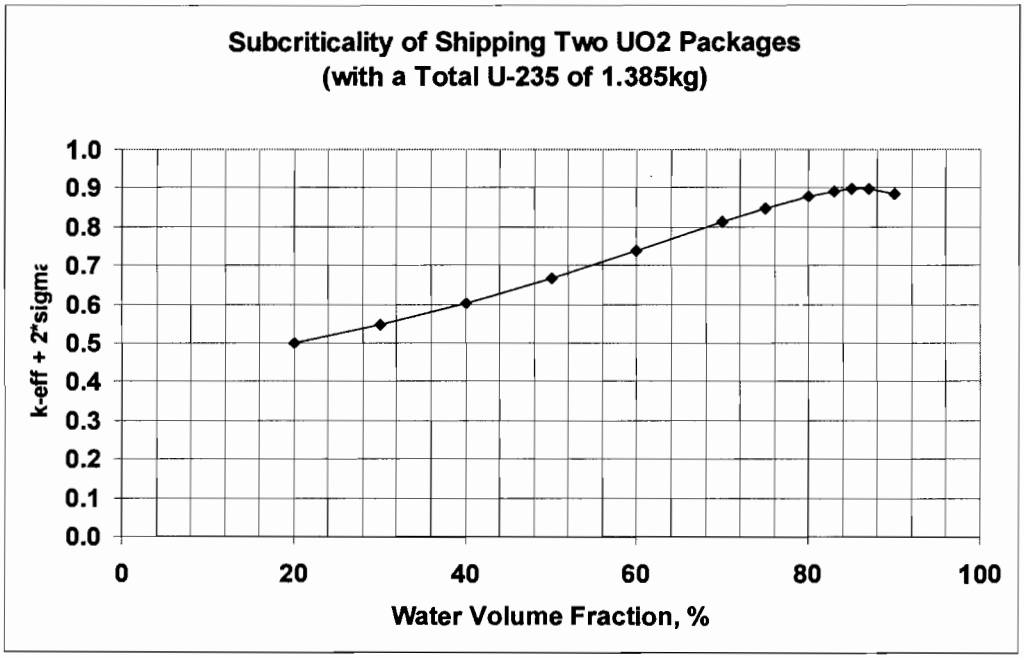

Figure 2. Subcrticality of a homogeneous mixture of 1.385 kg U-235 from two UO_2 packages and water in a spherical configuration with 30 cm of water reflection. The calculated maximum $k_{eff}+2\sigma$ (0.89703) occurs at a water volume faction of 87% and is well below the USL of 0.9271.

10 CFR 71.59 ***Standards for arrays of fissile material packages.*** 10 CFR 71.59 is also under Subpart E – Package Approval Standards of 10 CFR Part 71. 10 CFR 71.59(a) states that a fissile material package must be controlled by either the shipper or the carrier during transport to assure that an array of such packages remains subcritical. To enable this control, the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water:

(1) Five times "N" undamaged packages with nothing between the packages would be subcritical;

(2) Two times "N" damaged packages, if each package were subjected to the tests specified in §71.73 ("Hypothetical accident conditions") would be subcritical with optimum interspersed hydrogenous moderation; and

(3) The value of "N" cannot be less than 0.5.

As previously discussed and independently confirmed in this report under 10 CFR 71.55, a spherical safe mass limit of 1.685 kg would allow any two of the 75 Type A drums containing the LEU oxide to be shipped and the packages shall remain subcritical under HAC. This satisfies 10 CFR 71.59(a)(2) with two times "N" damaged packages under HAC with optimum

interspersed hydrogenous moderation, where N = 1; this also satisfies 10 CFR 71.55(a)(3) since N is greater than 0.5.

Appendix F of ORNL/NTRC-20, Rev. 1 contains supplemental criticality safety analyses that can be used to satisfy the requirement in 10 CFR 71.59(a)(1), i.e., five times "N" (or 5 with N = 1) undamaged packages with nothing between the packages would be subcritical. The relevant Appendix F results pertain to calculations for stacking arrays of either 76 or 14 Type A drums, each containing the LEU oxide with ^{235}U enrichment of 2.9%. Specifically, Tables 8, 10, and 12 of Appendix F contain the results for arrays of Type A drums without water between the drums. The highest calculated values of $k_{eff} + 2\sigma$ are 0.8824, 0.8883, and 0.8759, respectively, for stacking arrays of (4 x 19), (2 x 38), and (2 x 7) of Type A drums, and they are all lower than the USL of 0.9271.

Criticality Safety Index (CSI)

10 CFR 71.59(b) states that the CSI must be determined by dividing the number 50 by the value of "N" derived using the procedure specified in 10 CFR 71.59(a). Thus for N = 1, CSI = 50/N = 50.

10 CFR 71.59(c) states that for a fissile material package which is assigned a CSI value –

(1) Less than or equal to 50, that package may be shipped by a carrier in a nonexclusive use conveyance, provided the sum of CSIs is limited to less than or equal to 50.

(2) Less than or equal to 50, that package may be shipped by a carrier in an exclusive use conveyance, provided the sum of CSIs is limited to less than or equal to 100.

Since CSI = 50, an exclusive use conveyance allows any two (2) or a non-exclusive use conveyance allows only one (1) of the 75 Type A drums containing the LEU oxide to be shipped, while satisfying all requirements in 10 CFR 71.55 and 10 CFR 71.59. The Project Maximus application requests shipment by the exclusive use conveyance.

Regulations for Type A packaging

In response to the Q0 review,[1] the ONRL/NTRC-20, Rev. 1 document has included Appendix C Procurement Specification for UN1A2, Type A drums (ORNL Specification No. 100-1A2-0007), Appendix D Container preparation and Filling Instructions (ORNL-PKG-05 – for Type A Use), and Appendix E Compliance Summary with 49 CFR Requirements for Type A Packaging. The EM-60 staff reviewed these appendices and found them acceptable to meet the 49 CFR requirements for Type A packaging.

SUMMARY

The EM-60 staff has completed the technical review of the ORNL/NTRC-020, Rev. 1 document. The EM-60 staff has performed independent analysis and confirmed criticality safety of the shipment request of any two of the 75 LEU oxide packages in Type A drums in an exclusive use conveyance. The ORNL/NTRC-020, Rev. 1 is determined to be acceptable in providing the technical basis that meets the regulatory safety requirements in 10 CFR Part 71 and 49 CFR 173 for a Certificate of Compliance.

References:

1. Q0 Review of "Safety Basis for Certification of Project Maximus LEU Type A Drums as a Type AF Packaging Configuration, ORNL/NTRC-020, Vol. 1 to 3, Rev. 0, June 2006," DOE Memorandum, Dr. James M. Shuler (EM-60) to E. Ruthowski (NE-60), Nov. 21, 2006.

2. Safety Basis for Certification of Project Maximus LEU Type A Drums as a Type AF Packaging Configuration, ORNL/NTRC-020, Vol. 1 to 2, Rev. 1, February 2007.